Mint Industry Research Council

Pesticide Environmental Stewardship Strategy for the US Mint Oil Industry

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Integrated Pest Management (IPM) Strategy for the US Mint Oil Industry

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1.1 Introduction

More than 150,000 acres of peppermint and spearmint are grown commercially in the far-western and mid-western United States (Table 1). Although acreage of these crops fluctuate according to demand and price, both peppermint and spearmint are generally in high demand in both the U.S. and foreign markets. Currently, the Pacific Northwest ranks as the worlds leading producer of peppermint and spearmint oil; Oregon ranks as the number one peppermint producing state while Washington state is the largest producer of spearmint oil.

Both peppermint and spearmint are economically important agricultural commodities not only in states that grow them but to the U.S. economy as well. Annual sales of the two oils in 1994 was approximately 12 million pounds, with 8 million pounds of peppermint oil and 4 million pounds of spearmint oil going to market. The farm gate value of this oil is worth $125 million to $160 million each year, depending on price. This translates to a $3.5 billion dollar domestic market. Future market expansion of mint-flavored products will be in both areas that have well developed "mint" tastes and in other areas, especially in Europe and the Pacific Rim. Consumption of U.S. peppermint and spearmint oils is dominated by the chewing gum and toothpaste industries which use about 90% of the oil produced; lesser amounts are used in the confectionery, pharmaceutical and liqueur flavoring trades.

Many pests, including weeds, are known to infest peppermint and spearmint. If not managed effectively they can: (1) destabilize the supply and quality of mint oil; (2) significantly increase mint production costs; and (3) decrease the advantage presently held by U.S. mint growers over foreign competition. To ensure the continued viability of U.S. mint production, we propose a cooperative pest management strategy with EPA that: (1) is economically advantageous to mint growers; (2) relies on the most environmentally safe pest control tactics that can be adopted in a practical fashion; and (3) strives to reduce our overall reliance on synthetic chemical pesticides. For the purpose of this report, the generic definition of pesticide will include insecticides, miticides, fungicides, nematicides and herbicides. Pests will be defined as arthropods (insects type pests), diseases, nematodes and weeds.

Table 1. Summary by mint growing districts for peppermint and combined districts for spearmint: 1995 acreage, 1994 yields (lb oil/acre), average yields based on the last five years (lb oil/acre), and 1995 average price paid ($ per lb oil).

District	1995 Acreage	1994Average Yield (lb. oil/acre)	5 Year Average Yield (lb. oil/acre)	1995 Average Price of Oil ($/lb oil)
Peppermint				
Central Oregon	15,548	56.3	56.0	17.00
Idaho	23,224	75.8	73.1	16.00
LaGrande	6,916	67.2	60.7	16.00
Montana	9,193	66.4	62.0	15.00
Willamette	25,404	79.8	76.1	16.00
Washington	32,714	88.8	89.1	12.00
Midwest (IN,MI, WI)	36,000	42.0	38.0	13.50
Spearmint				
Farwest (WA,ID,OR)	15,000	110.0	115.0	12.00
Midwest	14,400	41.0	34.0	12.00

1.2 Current State of Integrated Pest Management

As for many agricultural commodities, the U.S. mint industry has relied heavily on chemical synthetic pesticides since the advent of DDT in the 1940's. Fortunately, over the last 25 years our industry has invested over 75% of its research budget towards non-chemical approaches to pest control (Mint Industry Research Council (MIRC) and State Commodity Commission Research Abstracts, 1970-present). Our trend towards adopting non-chemical approaches to pest management is likely to continue because: (1) non-chemical alternatives are often more cost effective than conventional pesticides; (2) fewer pesticides are available because of the re-registration process and the high cost of developing new ones; (3) pesticides are more difficult to register, especially on minor crops; (4) pest resistance has rendered many pesticides less effective; and (5) growers are more aware of environmental concerns. For these reasons, mint growers are increasingly interested in adopting more intensive IPM programs.

1.2.1 Definition of Integrated Pest Management

There is much confusion and debate surrounding the definition of IPM. For our purposes, we suggest the following definition: IPM is the intelligent selection of all available pest control tactics in a manner that is both cost effective and least harmful to non-target species and the outside environment. IPM tactics include: (1) pest prevention strategies; (2) monitoring for pests and natural enemies; (3) economic treatment thresholds for pests; (4) improved pesticide application techniques; and (5) pest control tools that include cultural, biological and chemical methods. In addition to the above, pesticide resistance management

(PRM) and management of the other crops grown in conjunction with mint (Integrated Crop Management or ICM), must be considered in an effective IPM program.

IPM may be viewed as a continuum from intensive IPM to non-IPM. Growers are using intensive IPM when they adopt research-based monitoring to estimate population densities of pest and beneficial organisms, compare these densities to known thresholds, and treat with the most selective pesticides possible. Conversely, growers who treat with pesticides on a calendar basis without regard to pest densities, and who use non-selective pesticides are not following IPM. Most IPM programs on mint presently fall in between these two extremes.

1.2.2 Overview of important pests in mint

Arthropods

Several arthropod pests (insects and their close relatives) are known to economically damage stands of peppermint and spearmint (Berry and Fisher 1993, Lacy et al. 1981, Rice-Mahr and Wyman 1994). Important pests include spider mites (Family: Tetranychidae); cutworms and loopers (Family: Noctuidae); the mint root borer (*Fumibotys fumalis*); root weevils (*Otiorhychus* spp.); the garden symphylan (*Scutigerella immaculata*); the mint flea beetle (*Longitarsus ferrugineus*); grasshoppers (*Melanopus* spp.); wireworms (*Ctenicera* sp. and *Limonus* sp.); the mint stem borer (*Pseudobaris nigrina*); and aphids (*Ovatus cratagarius* and other species in the family Aphididae). Moreover, plant stress caused by arthropods above economic treatment thresholds may increase the severity of Verticillium wilt (Hollingsworth 1981). The biology and management of these pests are reviewed by Berry and Fisher (1993). Occasional and potential mint pests include the painted lady butterfly, cucumber beetle, whiteflies, thrips, grubs, craneflies and the cranberry girdler. A summary of current arthropod management tactics and future management alternatives are presented in Table 2.

Table 2. Overview of arthropod pests and their management. Based on 1991 MIRC survey of researchers and state mint commissions.

Key Insect Pests	Primary Chemical	effect*	Cultural Control	effect*	Biological Control	effect*	Future Alternatives
soil cutworms	Lorsban	5	grass control	?	predators	?	IGR (Confirm 2E)
	Orthene	4	tillage	?	parasitoids	3	nematodes
			clean roots	2			mating disruption
foliar cutworms	Orthene	4	plant vigor	?	predators	3	IGR (Confirm 2E)
	Lannate	3			parasitoids	4	viruses
					B.t.	1	mating disruption
loopers	Orthene	4	plant vigor	?	predators	?	IGR (Confirm 2E)
	Lannate	3			parasitoids	4	viruses
					viruses	3-4	mating disruption
root weevils	Orthene	3	clean roots	4	predators	?	Cryolite bait
	Malathion	1	rotation	4	BioVector[1]	2	nematodes
symphylans	Dyfonate	4	rotation	3	predators	?	Mocap
							Biotechnology
mint root borer	Lorsban	3	tillage	3	BioVector	4-5	Mocap
			rotation	4	predators	?	mating disruption
					parasitoids	?	
Secondary Pests							
spider mites	Comite	4	flaming twice	4	predators	4	predator releases
	Kelthane	2	flaming once	1			selective miticides
aphids	Orthene	4			predators	4	predator releases
	MSR	3			parasitoids	3	selective aphicides
mint flea beetle	Lannate	3	tillage	1	predators	?	nematodes
	Malathion	2	rotation	4			Cryolite bait
	Vydate	1					selective insecticides
mint stem borer			clean roots	?			evening Orthene
			rotation	?			Cryolite bait
Sporadic pests							
false celery leaftier	Orthene	5			?		IGR (Confirm 2E)
painted lady	Orthene	5			?		IGR (Confirm 2E)
grasshoppers	Orthene	5			?		
wireworm	Dyfonate	4			?		Mocap
cucumber beetle							BioVector?
thrips							predator mites?

*Key to effect (effectiveness): 0 = no effect, 5 = excellent control, ? = unknown effectiveness
[1]Insect killing nematodes

Diseases
Peppermint and spearmint are hosts to pathogens that cause economic damage to mint. Presently the most important diseases include Verticillium wilt of mint (*Verticillium dahliae*), at least one species and several strains of mint rust (*Puccinia menthae*), and powdery mildew (*Erysiphe cichoracearum*). Other pathogens capable of causing disease on mint include *Cephalosporium*, *Sclerotinia*, *Phoma*, *Septoria*, and non-specific stolon decline, complex of *Fusarium*, *Rhizoctonia*, *Sclerotinia*, *Alternaria*, *Phoma* and *Pythium* (Green 1960, Sawada and Green 1963, Stevenson 1991, 1995 Pacific Northwest Disease Control Handbook). A summary of management tactics used for disease and nematode control are summarized in Table 3.

Because Verticillium wilt is a major impediment to long term mint production, a short overview of this disease is presented here. Verticillium wilt of mint is caused by the fungal pathogen *Verticillium dahliae*. Over 50 percent of the mint industry's research budget is invested in managing this disease, primarily through development of wilt tolerant varieties. Either directly or indirectly, mint IPM programs revolve around managing Verticillium wilt.

Once a field is contaminated with wilt, the spores can remain in the soil for long periods of time and infect future mint plantings. The survival mechanisms which make Verticillium such a difficult pathogen to control, include: (1) the persistence and durability of its survival structure, the microsclerotia; (2) the ability to subsist on a variety of alternate crop and weed species; (3) the potential to survive on dead organic matter as a saprophyte; and (4) the lack of effective fungicides.

This disease was transported throughout the midwest on contaminated root stock. During the 1930's, peppermint production in four Michigan counties was abandoned because of Verticillium wilt. Between 1949 and 1959, the number of midwestern mint farms decreased from 1681 to 473 (Vessels 1984). Most of the remaining growers confined their mint to small acreage's, and although they constantly moved peppermint to new land, the disease spread. By 1952, growers in the far-west producing districts requested an embargo against midwestern rootstock to prevent the introduction of wilt. During this decade, mint production in Oregon and Washington surpassed that of the midwest for the first time (Vessels 1984).

Presently, the western mint growing regions are experiencing difficulties with wilt as well. For example, in Oregon it is estimated that half of all mint fields are infested with this disease (Koepsell, per. comm.). Also, most of the irrigated acres in western and central Oregon have been planted to mint at least once before, and a high percentage of this acreage was removed because of wilt. Because growers are often unsure about a field's history, they are reluctant to plant mint because of possible crop failure. The MIRC and state mint commissions are continuing to contract with university researchers to learn more about this disease. This research will hopefully lead to the development of a soil bioassay that can detect the mint strain of Verticillium before fields are planted to mint.

Genetically manipulated peppermint plants tolerant to wilt but not immune, were first developed in the early 1970's (Murray 1970, Lacy et al. 1981). Although planting wilt tolerant root stock has been effective at slowing the spread of wilt, symptoms often appear in the first year of production on soils previously infested with the mint strain of this disease. Moreover, wilt tolerant varieties generally yield less than their parent standard (Crowe 1994, Johnson 1994, Welty and Gray 1994). Verticillium severity will also increase if mint is grown under stress. Stress may result from harsh climates, inadequate irrigation, insufficient fertilization, herbicide use or damaging populations of arthropods and nematodes (MIRC Research Abstracts 1986-present).

Nematodes

Plant parasitic nematodes are another pest problem facing mint growers in the far-west and midwest (Pinkerton 1983, Green 1984, Ingham et al. 1991, Santo et al. 1991). Laboratory research has shown that the root lesion nematode (*Pratylenchus penetrans*), in the absence of wilt, can reduce foliar production up to 46% and root growth by 86% (Bergeson and Green 1979). Pinkerton (1983) demonstrated that root lesion nematode could reduce peppermint yields by 73% in Oregon. Research conducted by Pinkerton (1983) and Ingham and Merrifield (1993) have resulted in preliminary economic thresholds for this pest. Other nematode pests include the root-knot nematode (*Meloidogne hapla*) which reduced peppermint yields in microplots by up to 56% (Santo *et al.* 1986). In field studies done in Oregon, high populations of pin nematode (*Paratylencus* spp.) adversely affected peppermint growth (Ingham and Morris 1987) and the needle nematode (*Longidorus sylphus*) severely stunted peppermint plants (Horner 1955). Other nematode species infest mint but their affects on the crop and unknown (Merrifield 1990).

Nematode infestations not only reduce yield during a single season, but may also adversely affect mint vigor for the rest of the crop's life. Mint stands weakened by nematodes are unable to tolerate additional stresses such as those caused by harsh winter, insects and diseases (MIRC Research Abstracts 1987-present). Research has demonstrated that plant-parasitic nematodes interact with the pathogen *Verticillium dahliae* to increase the severity of wilt on mint, tomatoes and potatoes (Conroy et al. 1972). Interactions of nematodes and wilt on peppermint have resulted in yield losses up to 40% higher than losses due to Verticillium alone (Faulkner and Bolander 1969, Santo et al. 1986).

Table 3. Overview of some disease and nematode management tactics, their effectiveness, and future alternative management strategies. Based on 1991 MIRC survey of researchers and state mint commissions.

Key Diseases	**Primary Chemical**	**effect***	**Cultural Control**	**effect***	**Future Alternatives**
Verticillium wilt	fumigant	3	varieties	3	new varieties
			reduced stress	2-3	biotechnology
mint rust (peppermint)	Tilt	4	flaming	4	new varieties
					biotechnology
mint rust (spearmint)			early harvest	2	Tilt, Rally
powdery mildew	sulfur	3			
stolon decline			plowing	2	
nematodes					
lesion	Vydate	2-3	clean roots	1-3	new varieties
			vigorous roots	2-4	biotechnology
			liming	?	Mocap
pin	Vydate	1	clean roots	1-3	new varieties
			vigorous roots	2-4	
			liming	?	

* Key to effect (effectiveness): 0 = no effect, 5 = excellent control. ? = effectiveness unknown

Nematodes not only provide entry points for wilt invasions, but they also alter mint physiology which increases susceptibility to this disease (Faulkner et al. 1970). A summary of some management tactics used for disease and nematode control are summarized in Table 3.

Weeds

Many broadleaf and grassy weeds can reduce mint yields and adversely affect mint oil quality (Heap 1993, 1995 Pacific Northwest Weed Control Handbook). Important broadleaf weeds include Canada thistle, Kochia, field bindweed, salsify, pigweed, and prickly China lettuce. Grass weeds that commonly require intense management include barnyard grass, quackgrass, foxtails, and bluegrass. Because tillage has been shown to spread Verticillium wilt and compact the soil, the mint industry relies on the judicious use of herbicides in combination with hand hoeing to manage the majority of our weed problems.

1.2.3 Generalized pest management program

The following discussion is intended to provide the reader with a generalized overview of peppermint and spearmint management in the United States. Due to the wide variation in mint production practices, however, this summary will serve as a guideline only and should not be considered the only production system used. More specific information on IPM tactics follow this overview.

As early as December, growers initiate their weed management programs. This often consists of using the herbicides Sinbar, Goal, Prowl and Karmex to provide pre-emergence weed suppression. These herbicides are often applied in combination with Gramoxone to burn down winter annual broadleaf weeds and grasses. Management of noxious weeds is an important part of mint production because many weed species adversely affect the flavor of mint oil (Heap 1993). In the early spring when temperatures are mild, Buctril and Sinbar are applied separately to manage seedling broadleaf weeds; Sinbar has activity on some grassy weeds as well. In furrow irrigated mint, Prowl is applied to manage weeds at germination. Prowl is important in areas that irrigate by furrow because it has longer residual activity than Treflan. Longer residual activity is important in drier regions that use furrow irrigation because pre-emergence herbicides require rainfall for activation (Boydsten 1991, 1992, 1993); Treflan must be immediately incorporated to avoid degradation and this can spread Verticillium wilt. Later in the spring when temperatures become warmer, Basagran is used instead of Buctril to manage broadleaf weeds because it is safer to the mint. The herbicide Stinger may be applied in May or early June to suppress populations of Canada Thistle, Salsify and Prickly China Lettuce.

Spring tillage begins sometime in March before mint breaks winter dormancy. Tillage improves soil aeration, pH uniformity and soil nutrient distribution, and also reduces populations of the mint root borer (*Fumiboyts fumalis* G.) and several annual weed species (Talkington and Berry 1986). However, due to the threat of spreading Verticillium wilt, and exacerbating soil erosion and soil compaction, few growers are currently employing this practice on a regular basis (Horner 1955). In mint growing regions using furrow irrigation, fields may be rotary corrugated. This practice is effective at incorporating soil pesticides and reducing populations of the mint root borer (Pike and Glazer 1982). Unfortunately, however, rotary corrugation also spreads Verticillium wilt (Horner 1955, McIntyre and Horner 1973).

During the spring, fields are sampled for populations of soil cutworms, symphylans, root weevils, mint flea beetles, wireworms, stem borers, spider mites and plant parasitic nematodes. If pest density is determined to be above the economic treatment threshold, soil cutworms are managed by Lorsban, Orthene and Dyfonate and Dyfonate is used to suppress wireworms (Berry and Fisher 1993). Dyfonate and Lorsban are also used to manage populations of garden Symphylans. Wireworms, Symphylans and soil cutworms are especially damaging to new and weak stands of mint (Berry and Fisher 1993). Fields infested with damaging levels of mint flea beetle larvae may be treated with insect killing nematodes (Morris 1989), but the feasibility of this approach requires more research. Root weevil larvae may also be treated with insect killing nematodes, but this is currently a costly approach and the species of nematode available may not be the most effective (Takeyasu and Berry 1993). An alternative is to treat adult root weevils in the evening with Orthene. Research by Morris and Fisher (1995 in prep.) has shown this method to be effective if applications are timed properly.

Over threshold populations of plant parasitic nematodes are treated in the early spring with Vydate (Pinkerton 1983 and Merrifield 1990). Impregnating Vydate on fertilizer can suppress populations of Lesion nematode (Merrifield and Ingham 1994). Applying Vydate in this fashion, or by immediate incorporation with overhead sprinkler irrigation, can reduce disruption of beneficial insect and mite predators (Morris 1995). Fields should be sampled in early spring for populations of spider mites and predator mites. If the ratio of spider mites to predator mites is not adequate, low cost application of predator mites can often bring the association into balance (Croft 1975, Morris 1995, Coop and Croft 1995). If fields must be treated for spider mites, low rates of Comite are effective and does not disrupt predator mites (Croft 1975, Helle and Sabalis 1985, Croft 1990, Morris 1995). The mint stem borer is a little understood pest that affects mint primarily in Idaho (Baird et al. 1990). Fortunately, this pest appears to be confined to this region.

Disease management in the spring is a crucial component of IPM on mint. In western Oregon, fields may be propane flamed in the early spring to control mint rust (Koepsell 1992, personal communication). Double flaming in the spring is also effective at reducing populations of spider mites and small weeds (Morris 1995). Spring flaming is not practiced in other mint growing regions because unacceptable damage results due to shorter growing seasons and more severe winters. Spearmint rust is managed only by early harvest (Scotland 1991, personal communication). Harvesting spearmint fields early to manage rust results in severe yield reductions. Sulfur is applied to manage powdery mildew on mint which is a recurring disease problem in certain mint growing districts (Johnson 1992).

From about early June through harvest, fields are monitored for damaging populations of spider mites, foliar cutworms, loopers, and aphids. All four of these pests are frequently maintained below economic thresholds by natural biological control (Berry and Fisher 1993, Morris 1995). If they are found at levels above the threshold, Orthene is applied to reduce populations of cutworms, loopers and aphids. Comite and predator mites are applied to suppress populations of spider mites. Both Orthene and Comite are important components of IPM because they allow survival of natural enemies (Morris 1995). In western mint growing districts, damaging populations of mint flea beetles are treated with Lannate in early July after adults have emerged (Morris 1989, Berry and Fisher 1993). Also during this time, fields are hand hoed to eliminate weeds that escaped herbicide treatment. This serves to reduce the seed bank and slow the selection of herbicide resistant weeds (Appleby and Brewster 1992, Boydsten 1992).

Single cut mint is harvested as early as late July through September. Double cut mint is harvested first in June and again in late August through September. Fields are sampled in late August and early September for mint root borer. Populations of root borers exceeding the economic threshold are treated with Lorsban after harvest or BioVector (insect killing nematodes) before and after harvest (Pike *et al.* 1988, Takeyasu 1995). In the midwest, economically damaging populations of mint flea beetle adults are treated with malathion following harvest (Van Haren 1984, Vessels 1984).

After harvest, growers make the final decision about whether to keep a field in mint or rotate to another crop. This decision is based on economic factors which include levels of insects, weeds and diseases. Fields maintained in mint are often treated with Buctril in the fall to control small broadleaf weeds. Buctril is economical and safer to mint in the fall than in the spring (Appleby and Brewster 1992). In several mint growing regions, the spread of wilt is reduced by propane flaming in the fall (McInyre and Horner 1973). When new mint fields are established in the fall, management of Verticillium wilt consists of planting clean rootstock of wilt tolerant varieties (Murray 1970, Roberts 1990).

1.2.4 IPM management tactics

An effective IPM program for mint includes the following tactics: (1) prevention; (2) intensive monitoring of pests and their natural enemies; (3) use of pest economic injury levels (EIL) and economic treatment thresholds (ET); (4) biological control; (5) cultural control; (6) selective pesticides; (7) selective ways of using more disruptive pesticides; (8) pesticide resistance management; and (9) managing system interactions within mint and between other cropping systems. The U.S. mint industry has dedicated the majority of its research funding towards non-chemical approaches to pest management. Presently, the majority of mint growers are using one or more of these in their pest management programs. Presented in the following discussion is a brief overview of the current methods used to control pests (insects, diseases, nematodes, and weeds), how effective these methods are, and a general review of research conducted to date.

1.2.4.1 Prevention and sanitation

Because mint is a vegetatively propagated crop, movement of pests in the rootstock and associated soil is a constant concern. Procedures to include the planting of clean rootstock and sanitizing equipment are effective measures to prevent the spread of many diseases, nematodes, insects and weeds.

Arthropods

Several insect pests can be controlled by planting clean rootstock and sanitizing equipment. Examples include the mint flea beetle and mint root borer, which feed only on mint and have limited dispersal abilities. Although they have a wider host range, garden sympylans and root weevils may be managed with clean rootstock because they are limited in their ability to disperse. Other pests which include the mint stem borer and redbacked cutworm complex may also be managed to unknown degrees by using clean rootstock; however, more research is needed on their host range and dispersal. Pests such as foliar cutworms, loopers, aphids, grasshoppers and spider mites, are controlled to a lesser degree by sanitation because they move readily across a wide geographical area. To prevent the introduction of pests from one growing district to another, phytosanitary regulations and rootstock quarantines have been established in most mint growing districts. Moreover, a rootstock certification program has been established by the MIRC to insure that growers have access to clean roots.

Diseases and nematodes

Many diseases and nematodes are disseminated in rootstock, in water and on contaminated equipment. Soil borne diseases such as Verticillium wilt and plant parasitic nematodes are spread mostly in these ways. Although airborne diseases such as rust and mildew and probably controlled less effectively by sanitation, implementation of equipment sanitation procedures, rootstock certification and regional phytosanitary requirements play a role in slowing the spread of all mint diseases.

Weeds

The majority of weeds are also spread by contaminated rootstock and equipment. Roots of perennial weeds such as Field Bindweed and Quackgrass are spread along with mint roots and associated soil, as are seeds of such weeds as Groundsel and Pigweed. For these reasons, the preventative measures used for controlling diseases and insects are also important for managing weeds.

1.2.4.2 Intensive monitoring

Before an intelligent management decision can be made, accurate assessments of pest and natural enemy population densities are required. Too frequently management decisions are made in the absence of such information which results in unnecessary pesticide applications. Although the majority of research on monitoring has been done for insects, such procedures are justified for all pests (insects, diseases, nematodes and weeds). Presently, there are no established sampling methods for density estimation of diseases and weeds in mint fields.

Arthropods

Reliable sampling procedures are available for most insect and mite pests on mint (Berry and Fisher 1993). These methods may also be used to estimate densities of beneficial insect predators and parasites as well. With this information, pest densities can be compared with economic injury levels (EIL) and densities of natural enemies to determine if treatment intervention is necessary. Sampling programs for insects and mites employ leaf samples, sweepnets, ground searches, soil samples, Tulgren-Berlese funnel extraction and pheromone traps.

Nematodes

Nematodes are extracted from soil samples by density centrifugation and Baermann funnels, and from roots in mist chambers (Pinkerton 1983, Merrifield 1990, Ingham and Merrifield 1993). The most common nematode sampling procedure used in mint is to bulk multiple soil cores and root samples from a field into a single composite sample for extraction. Although effective sampling methods for nematodes exist, they are expensive to implement. Thus, few growers sample their fields for nematodes; most do not sample at all. This in unfortunate because unjustified nematicide applications are expensive and can disrupt biological control of insects and mites.

Diseases

The mint industry has funded research on soil sampling for Verticillium wilt, but results were inconclusive (Crowe 1993). An improved method of extracting wilt spores from soil may make this method more reliable (Crowe 1994). An effective method of estimating the density of Verticillium spores in a field prior to planting mint, would assist growers in deciding whether or not a viable mint stand could be established. A method for extracting sap from mint plants and testing the sap for Verticillium has been developed by Johnson (1992). This method may be valuable for evaluating mint rootstock grown in the greenhouse. Because current Verticillium assessment of certified mint plants is by visual means only, and because Verticillium can be present in plants exhibiting no symptoms (Johnson 1992), a more thorough method of assessing greenhouse stock may improve certification standards. The mint industry is presently funding further research on sampling methods for this disease. Presently, sampling methods designed to estimate the population density of plant pathogens are not available for other mint diseases.

1.2.4.3 Economic injury levels (EIL) and thresholds (ET)

In addition to knowing pest and natural enemy densities, growers must understand how these densities affect yield. It does not make economic sense to treat a pest population if the cost of doing so exceeds the savings in yield loss prevention. Treating fields that have pest densities below the economic threshold is not only monetarily wasteful, but may disrupt natural enemies and accelerate pesticide resistance.

Insects, nematodes, diseases and weeds

Economic thresholds have been established for many of the insect and mite pests on mint (Berry and Fisher 1993). Threshold levels for lesion nematode have been estimated by Pinkerton (1983) and Ingham et al. (1994). Although research on economic thresholds for Verticillium wilt has been hampered by the lack of reliable soil extraction methods for wilt spores (Crowe 1994), work is continuing on the refinement of soil extraction methods. The available information relating weed densities to yield loss and oil quality is review by Heap (1993).

When growing mint for oil, cosmetic appearance is inconsequential and economic thresholds are established based on yield loss alone. As long as yield is not economically affected, a certain degree of pest damage can be tolerated. This allows for the establishment of Economic Injury Levels that are higher than can be tolerated for crops using aesthetic tolerances.

1.2.4.4 Biological control

Biological control will save mint growers money through reduced pesticide costs and by extending the useful life of currently registered pesticides. Presently, targeting insects and mites represents the greatest potential for implementing biological control on mint. Less is known about the relationship between other mint pests (diseases, nematodes and weeds) and their natural enemies.

Arthropods

The proposed goal of IPM on mint is to encourage biological control by treating with pesticides only when economically justified, and when possible, by using pesticides and application methods that are less harmful to beneficial species. Because it is cost effective, biological control can be the foundation of arthropod IPM programs. Adoption of biological control will reduce production costs by reducing unnecessary pesticide applications and preservation of effective and lower cost pesticides.

Mint is an ideal crop for implementing biological control. First, mint is a perennial crop that requires frequent irrigation. This results in lush foliage and humid conditions which contribute to an ideal microenvironment for pest natural enemies. Second, mint is a perennial crop which creates a more stable ecosystem than most annual crops. This allows natural enemies to colonize and establish in mint fields. Third, agronomic practices employed by mint growers can be managed to conserve predators and parasites. Finally, as discussed above, mint grown for oil does not require a cosmetic tolerance. Because a certain pest density is required to support populations of pest natural enemies, low level pest densities are valuable, and in mint they do not require immediate pesticide intervention.

Three types of biological control are practiced in mint: (1) Conservation: agronomic practices are adjusted to conserve naturally occurring predators and parasites; (2) Augmentation: low numbers of natural enemies are released to establish populations in new fields and to improve the ratio of natural enemies to pests in fields where predator levels are too low, and (3) Inundation: High numbers of biological control agents are released in a manner similar to conventional synthetic pesticides.

Important natural enemies of mint pests include parasitoids in the fly and wasp orders; predators in the beetle, fly, true bug, and lacewing orders; spiders; centipedes; and pathogens to include viruses and fungi. Some of the known associations between insect pests and their natural enemies are summarized in Table 4. The arthropod pests most consistently controlled through conservation of natural enemies are aphids, loopers, cutworms, and spider mites (Berry and Fisher 1993, Morris 1995). Other arthropod pests are affected by natural enemies, but more research is required to identify the natural enemies and determine their effectiveness. For example, Berry (1973) showed that the predator mite (*Pergamasus quisquiliarum*) preyed on garden symphylans, but how effective they were at regulating populations of symphylans was not determined. In another study, Cacka (1982) demonstrated that predacious ground beetles fed on root weevil larvae in mint, but their role in controlling this pest is still unknown.

The U.S. mint industry has not only invested in research on naturally occurring predators and parasites, but also on augmentation and inundative release. Research on augmentation has involved the periodic release of Phytoseiid predator mites to control spider mites (Morris 1995). Augmenting mint fields with small numbers of predator mites has been an effective and economical strategy for controlling spider mites. To take full advantage of predator mites and other biological control agents, growers must use agronomic practices that allow for predator survival. To assist growers in fine tuning spider mite management, research on the relevance of spider mite to predator mite ratios is presently ongoing (Morris 1995).

Inundative strategies funded by the US mint industry include research on *Bacillus thurengiensis* (Bt) applied to control cutworms and loopers, and insect killing nematodes used to control mint flea beetles, mint root borers, and root weevils (Morris 1990 and Berry and Takeyasu 1993, Takeyasu 1995). Results of studies that tested two Bt formulations for controlling cutworms on mint have not been encouraging (Jim Calkin, Sandoz Inc. 1988 and Abbot Laboratories, personal communication). While Orthene provided acceptable control in these studies, Bt was unable to reduce cutworm populations below the economic threshold. These results agree with most field level applications. The ineffectiveness of Bt

Table 4. Mint pests known to be under varying degrees of natural biological control, and the natural enemies involved.

Pest	Parasitoids	Predators	Pathogens
aphids	<u>Hymenoptera</u>:	lady beetles	
	Aphidiidae	syrphid fly larvae	
		lacewings	
		nabid bugs	
		bigeyed bugs	
		spiders	
		pirate bugs	
loopers	<u>Hymenoptera</u>:	lacewings	nuclear polyhedrosis virus
	Chalcidae	nabid bugs	
	Braconidae	syrphid fly larvae	
	Ichneumonidae	spiders	
	<u>Diptera</u>:		
	Tachinidae		
foliar cutworms	<u>Hymenoptera</u>:	lacewings	
	Meteorus sp.	nabid bugs	
	Nepiera sp.	syrphids	
	Campoletis sp.	spiders	
root weevils		carabid beetles	fungi
		centipedes?	
soil cutworms	<u>Hymenoptera</u>:		
	Porizentinae		
	Copidosoma sp.		
spider mites		predator mites	
		pirate bugs	
		nabid bugs	
		bigeyed bugs	
		Cecidomyeid flys	
		lacewings	
		syrphid flys	
		spiders	

may be related to application methodology, environmental conditions, biology of the pest, or a combination of all three factors. Hopefully, research on new strains and more effective application methodologies will enable mint growers to use Bt effectively in the future. Research on the efficacy of insect killing nematodes has been more encouraging.

*Steinernema carpocapsae*is effective at controlling mint flea beetle and mint root borer (Morris 1990 and Takeyasu 1995). As a result of these studies, BioVector for mint is now commercially available to mint growers. Unfortunately, control of root weevils with BioVector has been less successful, probably because this nematode species prefers to remain near the soil surface while root weevils and commonly found deeper in the soil profile.

Diseases, nematodes and weeds

Less is known about biological control of diseases, nematodes and weeds than is known about arthropods. Reasons for this include: (1) the lack of readily available and proven biological control agents for these pests, and (2) potential negative interactions between biological control agents of arthropods and those for other pests. For example, arthropods introduced to control weeds may become prey for arthropods released to control insect pests. Nevertheless, the U.S. mint industry is willing to fund research on biological control in all pest categories. Stevenson (1993) evaluated antagonistic fungi against Verticillium wilt but results were inconclusive because he lacked an effective soil sampling method for Verticillium. Research has also been funded to evaluate suppression of lesion nematode on mint with insect killing nematodes, but again, results were not encouraging (Ingham and Berry 1995). The MIRC is presently funding Dr. Gerald Santo, nematologist, Washington State University, to investigate the effectiveness of other biological control agents against lesion nematode. Predatory nematodes are known to prey on lesion nematode, but their commercial development is hampered by lack of economic incentives and the lack of mass rearing procedures (Biosys, per. comm.). Dr. Rick Boydsten, a weed researcher with USDA, has proposed evaluating the effectiveness of a plant feeding mite for controlling field bindweed in mint, and Dr. Caroll Mallory-Smith, weed researcher, Oregon State University, has proposed to evaluate plant pathogens as biological control agents in mint. If successful, these projects will serve as examples of weed biological control in a cropping system. Currently, the majority of successes in biological control of weeds are in non-crop situations.

1.2.4.5 Cultural control

Cultural pest management tactics are important components of IPM on mint. Cultural tactics include planting pest tolerant mint varieties, crop rotation, sequence of rotational crops, propane flaming, and hand hoeing and tillage for weed control. Although the mint industry has supported the use of cultural tactics for many years (Green 1963), much additional research continues to be dedicated towards finding new cultural methods that are economically feasible.

Arthropods

Cultural control is effective for managing many arthropod pests on mint. Although primarily used for control of mint rust, double propane flaming in the spring is effective at suppressing spider mites in the Willamette Valley (Morris et al. 1991). Unfortunately, spring flaming can damage mint stands in growing districts with harsh climates and short growing seasons, so it is not usually practiced in those areas. Despite the benefits of spring flaming, it is also harmful to predator mites and this must be taken into consideration (Morris 1995).

Tillage in the late fall and spring is not only effective at reducing populations of mint root borers (Pike and Glazer 1982, Talkington 1983, Pike et al. 1988), but delays the onset of spider mites as well (Berry and Fisher 1993). However, tillage may also spread Verticillium wilt and increases soil compaction (Crowe 1993). Crop rotation is effective at controlling populations of mint flea beetles (Van Haren 1984, Vessels 1984, Morris 1990) and mint root borers (Berry and Fisher 1993). Planting vigorous rootstock is an important component of insect pest management because strong plants can better compensate for damage caused by arthropod pests (Fisher and Berry 1993).

Diseases and Nematodes

Cultural practices are also effective at managing mint diseases. The development of Verticillium-tolerant varieties has been a priority of the mint industry since the early 1970's (Murray 1970, Roberts 1990), and remains our highest priority to date. New avenues of variety development, particularly biotechnology, are presently funded by the MIRC (Croteau 1994, Sink and Lacy 1994, Weller and Bressan 1994). Propane flaming in the fall can reduce the spread of Verticllium by destroying innoculum in plant residues that remain after harvest (McIntyre and Horner 1973). Shorter crop rotation can also help to manage this disease (Nelson 1950). The MIRC is funding research on the efficacy and practicality of living mulches to control Verticillium and other pests (Johnson et al. 1994, Welty et al. 1994)l; however the practicality of these methods remains in question. For controlling mint rust, thorough propane flaming in the spring is effective in western Oregon (Horner per. comm.). Tillage and plowing in the midwest are helpful for managing mint rust and soil-borne diseases such as anthracnose fungi (Lacy et al. 1981). Ripping the soil in the spring prior to mint emergence helps warm the soil and reduce the incidence of stolon decline (Stevenson and James 1994). The planting of clean and vigorous rootstock is important for managing plant parasitic nematodes on mint (Lacy et al. 1981, Pinkerton 1983, Merrifield 1990).

1.2.4.6 Selective conventional pesticides

Because biological and cultural controls are not effective in all cases against every pest, conventional synthetic pesticides will continue to be an important component of IPM programs on mint. Conventional pesticides are the only tactic that can rapidly reduce a pest population below the economic injury level (Metcalf and Luckman 1982). Yet this attribute becomes problematic when natural enemy populations are also reduced. If chemical pesticides are necessary, applying those that are least harmful to pest natural enemies would help maintain biological control (Croft 1990, Morris 1995). Presently, most conventional pesticides are more harmful to pest natural enemies than to pests (Croft 1990); therefore, selective chemical pesticides are valuable and should be preserved.

An effective IPM strategy is to apply low rates of selective pesticides that reduce pest populations to a level where natural enemies can regain control (Croft 1975, Helle and Sabelis 1985). Because pesticides are often toxic to beneficial predators and parasites, research must be conducted to assess pesticide selectivity. The MIRC has supported studies on the effects of pesticides registered on mint, or in the registration process, on predator mites (Morris 1995). To encourage biological control of spider mites, the mint industry must play an active role in maintaining those pesticides that are less disruptive to predator mites. For example, Orthene (acephate) is less disruptive to predator mites than other alternatives in the carbamate or pyrethroid insecticide groups (Morris 1995). Another example is Comite which is more harmful to pest mites than beneficial ones. Growers can treat with low rates of Comite to adjust the ratio of spider mites to predator mites to favor predators (Croft 1975, Helle and Sabelis 1985, Morris 1995). The loss of Comite would seriously jeopardize biological control of spider mites unless selective pesticide alternatives are found (Jenkins et al. 1995 in prep). The U.S. mint industry is presently looking to register selective pesticides such as Vendex and Saavy for spider mite control, Confirm for cutworm and looper control, and Cryolite bait for root weevil control.

1.2.4.7 Selective use of disruptive pesticides

In some cases, pesticides that would normally kill large numbers of beneficial predators and parasites can be used effectively in ways that are more selective. Presently, several pests can only be managed economically with pesticides that are harmful to biological control agents; e.g. garden symphylans, wireworms, plant parasitic nematodes, soil cutworms, mint flea beetles, and weeds. However, disruptive pesticides can often be applied in ways that encourage at least partial survival of predators and parasites. Selectivity can be imparted by the timing and method of application, as well as the formulation used. For example chemigation or granular formulations of Lorsban and Mocap are less disruptive than broadcast applications (Morris 1995). Similarly, Ingham et al. (1993) showed that impregnation of Vydate on fertilizer was effective for suppressing root lesion nematode in mint, and impregnation is less disruptive to biological control agents than broadcast applications. Finally, the herbicide Gramoxone is more selective when applied in the late fall and winter because predator mites are dormant (Morris 1995).

1.2.4.8 Pesticide resistance management

If a pesticide is used on a regular basis, resistance will most likely develop in pest populations (NAS report 1986, Roush and Tabashnik 1990). Research supported by the U.S. Mint Industry has identified spider mite populations resistant to Kelthane (Morris 1995) and weed populations resistant to Sinbar (Boydsten 1993). The goal of resistance management is to delay or revert resistance, thus averting control failure (Croft 1990, Roush and Tabashnik 1990). Pesticides are becoming more expensive and often more difficult to register, especially for minor crops such as mint. A strategy that increases the useful life of important pesticides makes economic sense. An effective integrated resistance management (IRM) program for mint would rely primarily on biological control with pesticides being only applied when pest densities exceed the economic threshold. If pesticide treatment is necessary, however, then growers should use the most selective pesticide possible, apply the lowest effective rate to minimize disruption of biological control, and alternate among pesticides that have different modes of action. By following these guidelines, effective pesticides will remain viable for longer periods of time.

1.2.4.9 Management of system interactions

Too frequently, management for one pest does not take into consideration their impact on other pests. This often creates additional pest problems. For example, treating with certain herbicides to control weeds can cause disease and mite outbreaks. Johnson et al. (1993) documented increased Verticillium and powdery mildew severity in mint plots treated with the herbicides Sinbar and Command, respectively. Also, treating weeds with Gramoxone during periods of predator mite activity can increase spider mite problems (Morris 1995). Rootstock propagation methods can enhance the severity of certain diseases. For example, rootstock produced through meristematic tissue culture appears to increase the incidence of mint rust in Montana (Welty 1994). Management of plant parasitic nematodes can reduce the severity of Verticillium (Faulkner et al. 1970), but nematicides can disrupt predator mites (Morris 1995). To avoid or manage these situations in the future, agronomic practices on mint must be evaluated for their overall impact on the mint production system.

1.2.5 Surveys of pesticide use, importance, and needs

As discussed above, synthetic chemical pesticides will continue to be an indispensable part of mint IPM programs for some time to come. Our proposed strategy is to use them only when necessary and to use those least harmful to non-target beneficials and the outside environment. To insure the viability of the U.S. mint industry, we must preserve conventional synthetic pesticides that control pests where no economical alternatives are available, and obtain new pesticide registrations as required.

To address the impending loss of pesticides resulting from re-registration, the mint industry conducted a series of surveys on pesticide use and importance. During 1990, mint researchers and state commodity commissions completed an MIRC-sponsored questionnaire designed to rate registered pesticides in order of their importance. In 1991, MIRC conducted a pesticide use survey to gather similar information from mint growers nationwide. These data are summarized in Tables 5 and 6. In 1992, the Oregon Mint Commission contracted with Oregon State University to conduct a state-wide pesticide use survey on the importance and effectiveness of pesticides on mint in Oregon (Jeppson 1995). Idaho mint growers conducted a survey in 1993 to assess pesticide importance. In 1995, Rocky Lundy obtained a survey on pesticide use compiled by the National Center for Food and Agricultural Policy, parts of which are presented in Table 5. Based on these surveys, a pesticide priority list was established which is summarized in Table 7. This information is being used to decide which pesticides are critical to maintain and also to provide a benchmark for long term comparison of pesticide use patterns on mint.

The mint industry is currently supporting the re-registration of bromoxynil, diruon, malathion and napropamide. With the exception of bromoxynil, the importance to the U.S. mint industry of re-registering these pesticides is moderate to low. However, the decision was made to support re-registration because diruon and napropamide are effective at reducing terbacil resistant pigweed in some growing areas, and malathion is important in the midwest for mint flea beetle suppression.

Table 5. Percentages of mint acres treated in the U.S. with pesticides and pounds of active ingredient per acre applied. Based on results of 1991 MIRC mint growers survey and 1995 pesticide summary report prepared by the National Center for Food and Agricultural Policy (NCFAP).

Percent of U.S. Peppermint (Pep) and Spearmint (Sp) acres treated with pesticides and pounds of active ingredient applied

	MIRC % acres treated		NCFAP combined mint	
Pesticide	Pep	Sp	% acres treated	lbs ai applied
acephate	36.9	6.1	50.0	87,203
bentazon	50.2	69.4	76.0	174,138
bromoxynil	29.1	7.4	55.0	24,447
chlorthalonil	0.5	5.5	1.0	2,168
chlorpyrifos	21.2	11.0	27.0	66,340
dichloropropene	0.2	0.3	--	--
dicofol	5.6	1.7	7.0	12,612
diuron	6.8	0.0	1.0	1,544
fonofos	12.1	0.0	21.0	66,013
malathion	20.1	20.9	8.0	5,586
metam-Na	0.3	0.0	--	--
methomyl	1.3	0.2	10.0	16,087
napropamide	1.0	0.0	1.0	3,136
oxamyl	15.3	0.1	33.0	64,573
oxydemeton-M	4.1	1.1	13.0	15,948
oxyfluorfen	21.7	1.8	18.0	10,077
paraquat	26.6	0.5	25.0	19,881
pendimethalin	5.9	13.0	15.0	44,836
propargite	47.6	3.7	46.0	144,869
sethoxydim	42.5	42.8	36.0	14,909
sulfur	32.8	29.7	45.0	223,206
terbacil	89.6	92.1	84.0	127,607
trifluralin	2.6	5.2	1.0	445

Table 6. Percentages of peppermint and spearmint acres treated with pesticides in U.S. mint growing districts. Information is based on the 1991 MIRC grower survey.

	Percent of peppermint and spearmint acres treated in the US by district											
	OR (West)		OR (Central)		WA		ID		MT		Midwest	
Pesticide	pep	sp	pep	sp	pep	sp	pep	sp	pep	sp	pep	sp
acephate	74.7	--	61.8	--	36.4	4.1	79.9	0.0	98.1	--	9.1	7.2
bentazon	25.1	--	48.8	--	11.6	17.0	43.2	60.8	53.5	--	88.7	81.8
bromoxynil	82.2	--	54.7	--	31.9	18.4	38.6	53.8	4.3	--	0.2	0.3
chlorthalonil	5.8	--	0.0	--	0.0	0.0	0.0	0.0	0.0	--	1.7	19.3
chlorpyrifos	56.3	--	41.5	--	21.7	0.2	26.2	24.4	0.0	--	1.1	13.7
dichloropropene	2.6	--	1.5	--	3.1	1.4	0.0	0.0	0.0	--	0.0	0.0
dicofol	7.7	--	57.3	--	26.8	8.7	6.4	8.2	49.9	--	0.0	0.0
diuron	32.3	--	0.0	--	0.0	0.0	0.0	0.0	0.0	--	0.0	0.0
fonofos	56.0	--	0.0	--	0.0	0.0	0.0	0.0	0.0	--	0.0	0.0
malathion	8.3	--	33.8	--	10.9	1.0	4.8	0.0	0.0	--	47.9	48.9
metam-Na	1.3	--	6.5	--	0.0	0.0	0.0	0.0	0.0	--	0.0	0.0
methomyl	1.0	--	2.0	--	0.0	0.0	0.0	0.0	15.8	--	0.0	0.0
napropamide	4.9	--	0.0	--	0.1	0.0	0.0	0.0	0.0	--	0.4	0.0
oxamyl	54.5	--	40.2	--	15.3	0.0	--	--	--	--	--	--
oxydemeton-M	1.8	--	12.6	--	27.5	16.7	14.2	67.5	0.0	--	11.0	0.0
oxyfluorfen	78.3	--	33.6	--	0.0	0.0	5.6	0.0	--	--	8.2	0.0
paraquat	94.1	--	42.7	--	4.8	2.3	18.6	20.3	88.9	--	0.0	0.0
pendimethalin	9.1	--	0.0	--	9.1	18.2	33.9	17.6	--	--	--	--
propargite	32.6	--	100.0	--	66.3	10.2	78.4	28.0	13.1	--	0.0	0.0
sethoxydim	7.5	--	4.8	--	23.4	25.0	13.8	17.6	52.8	--	68.3	51.3
sulfur	0.9	--	6.6	--	35.5	41.3	21.3	26.8	--	--	0.0	0.0
terbacil	92.5	--	96.7	--	83.7	91.8	77.1	97.9	100.0	--	96.7	100.0
trifluralin	0.4	--	0.0	--	23.6	26.4	0.2	0.0	0.0	--	--	--

Table 7. Relative importance of currently registered pesticides on mint. Based on 1991 survey of mint researchers and state commodity commissions.

Pesticide	Importanc e	Why pesticide is or is not important
Fungicides		
sulfur	8	Cost effective and efficacious on powdery mildew but may lower oil quality.
chlorthalonil	2	Maintained because it is the only fungicide registered on mint and has limited e
Herbicides		
terbacil	10	Despite resistance, still very effective in all districts. Good broadleaf & grass control.
clopyralid	10	Consistent control of Canada thistle, salsify, and prickly China lettuce.
oxyflurofen	9	Good suppression of broadleaf weeds resistant or tolerant to terbacil.
bromoxynil	8	Good post-emergence control of broadleaf weeds but can damage mint.
bentazon	8	Fair control of emergent broadleaf weeds.
paraquat	8	Good activity on emergent grass and broadleaf weeds during dormant season.
pendimethalin	8	Excellent pre-emergence control of weeds in furrow irrigated mint, especially Kochia.
sethoxydim	8	Fair to good post-emergence control of several grassy weeds.
diuron	7	Fair to good post-ermgence control of weeds but may damage mint.
trifulralin	3	Fair pre-emergence control of weeds, but requires incorporation which spreads wilt.
napropamide	2	Good control of terbacil resistant weeds, but is costly and low residual activity.
Insecticides		
acephate	10	Cost effective on cutworms, root-weevils, aphids. Less disruptive to predator mites.
propargite	10	Despite resistance is cost effective, efficacious on mites and soft on beneficials.
chlorpyrifos	8	Suppression of root borer and soil cutworms. Less disruptive if chemigated.
fonofos	8	Only insecticide that adequately suppresses symphylans in western Oregon.
oxamyl	6	Only registered nematicide. Inconsistent activity and toxic to predator mites.
malathion	5	Used for suppression of mint flea beetle in the midwest.
methomyl	5	Only insecticide that adequately suppresses flea beetle in the Pacific Northwest.
metam-Na	4	Expensive, but is effective at suppressing wilt, especially on rootstock fields.
dichloropropen	4	Expensive but effective at suppressing wilt when combined with chloropicrin (C-17).
B.t.	2	Present formulations offer very inconsistent results.
dicofol	1	High levels of spider mite resistance and is disruptive to predator mites.

Key: 0=not important, 10=very important.

2. Barriers to IPM adoption

There are formidable barriers to IPM implementation in mint. The following examples have been identified as impediments to adoption of intensive IPM on mint. These barriers are discussed under the following headings: (1) regulatory and administrative; (2) economic; (3) lack of information and training; and (4) social.

2.1 Regulatory and administrative barriers

(1) *Loss of minor crop pesticides*
Due to the rigors of pesticide re-registration and increased pesticide scrutiny, several pesticides that are crucial to mint production are now, or may be, in jeopardy. Examples include Buctril, Comite, Goal, Orthene, Prowl and Tilt. Replacements would be expensive and slow to register, and for resistance management purposes, at least one other pesticide that is effective but with a different mode of activity is required. Comite is especially important because it does not pest natural enemies which enables mint growers to practice biological control.

(2) *Lack of new selective pesticides*
Because of the increasing costs of development and registration, fewer new selective pesticides are available. While insect growth regulators (IGR's) have been available in places such as Europe for many years, they have not been readily available for use in the U.S. until recently. This has been an area of enormous frustration to IPM researchers on many crops. Presently, there appears to be progress in this area and we support this trend.

(3) *Slow pace of pesticide registration.*
The mint industry needs new pesticides that are compatible with biological control and resistance management. While we empathize with the regulatory burden of pesticide registration, some framework is necessary to reduce the time spent obtaining a tolerance. The mint industry typically has waited 10 to 20 years for a pesticide tolerance. Replacement pesticides, especially those that are classified as "safer"and complement resistance management, need to be registered more quickly. There is compelling evidence that switching amoung pesticides with different modes of action is an effective resistance management strategy. However, because resistance management is not a criteria for section 18 emergency exemptions, a vulnerable pesticide may be lost to resistance before a complementary one is finally granted a label.

(4) *Lack of lower risk recognition associated with selective pesticides*
If by using a pesticide such as Comite, growers are able to treat less frequently through biological control, then this should weigh heavily in deciding a pesticide's regulatory fate. The same applies for using less selective pesticides more selectively. For example, cancellation of granular formulations should be reviewed more closely because they are often less toxic to pest natural enemies. Perhaps a crop by crop review of potential off

target effects of granular formulations would be warranted. Also, the mint industry can provide more clear documentation of pesticide importance, selectivity and magnitude of use, through avenues such as pesticide use surveys and the Pesticide Benefits Assessment model (PBA). We are presently cooperating with Oregon State University on a PBA project for Comite.

2.2 Economic barriers

(1) *The perceived high cost of IPM programs.*

One reason growers adopt this view is because unrealistic pricing expectations are generated through government sponsored pilot programs. These well intended projects designed to demonstrate the benefits of IPM, often backfire on minor crops because private industry is unable to match the low prices suggested by them. When a thorough economic evaluation is conducted on the costs associated with IPM, however, it is no wonder that more privately funded programs are not initiated. Although it has been suggested that growers who adopt intensive IPM be given tax incentives, in the long run IPM programs must justify their existence on the merit of cost savings alone.

(2) *The low price of conventional pesticides*

It is difficult to justify the higher cost of "safer" pesticides when low cost alternatives are still available. Adoption of newer, higher priced technologies will be slow unless growers are forced to use them in a crisis. However, growers may accept higher pesticide costs if the benefits incurred through resistance management and enhanced biological control are effectively communicated, but this will require education of the grower community.

2.3 Lack of information and training

(1) *Lack of understanding*

Growers frequently associate IPM with radical environmentalism. Many staunch opponents of pesticide use, and proponents as well, have promoted this misconception because it serves their purpose. In order to clear up any misconceptions that IPM equates to radical environmentalism, proponents of true IPM need to be as effective at disseminating their message as are the proponents for and against pesticide use.

(2) *Intensity of management required by IPM*

Intensive IPM is often not adopted because of the high level of training and the vast amount of information required for success. There is no question that applying a pesticide on a routine basis is easier than intensive scouting, use of economic thresholds, and tactics such as spot treatment with selective pesticides. The level of understanding and information necessary to practice IPM often results in its lack of adoption.

2.4 Social barriers

(1) *Familiarity and success with conventional pesticides*

Since the 1940's, many growers have adopted conventional synthetic pesticides as a primary tactic of IPM. Because of their effectiveness, ease of use and low cost, it has been difficult to argue otherwise. Recent developments such as increases in the cost of pesticides, pesticide resistance, and necessity of containing production costs, suggest other pest management tactics should be seriously considered.

(2) *Uncertainty and risk associated with IPM*

Growers generally perceive IPM to be more risky than applying pesticides on a routine basis, and risks are often higher for farmers today. Many growers today cannot absorb a crop failure as well as they could 30 years ago. Also, the same ground that used to support only one family must frequently support multiple families, and, because of the high costs associated with farming, growers are more highly leveraged from season to season. One crop failure can mean economic disaster, so risk is an issue that is taken very seriously. I would argue, however, that over reliance on conventional pesticides is risky as well. Unnecessary pesticide applications are not only expensive, but the pace of resistance development increases which can render moderately priced pesticides ineffective.

3. Strategy for Implementation of IPM on Mint

To restate our proposed objective: the goal of IPM on mint should be to intelligently use all available pest control options in a manner that is both economical and least disruptive to the non-pest environment. An effective IPM program for mint should include the following tactics: (1) prevention, (2) intensive monitoring of pests and their natural enemies, (3) use of pest economic injury levels (EIL) and economic treatment thresholds (ET), (4) biological control, (5) cultural control, (6) selective pesticides, (7) selective ways of using more disruptive pesticides, (8) pesticide resistance management, and (9) managing system interactions within mint and between other cropping systems. For arthropod pests, we should encourage biological control by treating with insecticides only when economically justified, and, when possible, by using pesticides and application methods that are less harmful to beneficial species. The following are information transfer and research avenues identified by the IPM committee that would enhance mint pest management.

3.1 Education and information dissemination

(1) *Encourage grower participation at MIRC and state grower organizations and meetings*

Better grower participation at MIRC and state grower organizations will generate research ideas and facilitate dissemination of information related to IPM practices.

(2) *Addendum to MIRC newsletter*

Oregon State University previously published a newletter providing specific information on the management of arthropods, nematodes, diseases and weeds in mint. Although well received in Oregon, bugetary constraints at OSU forced cancellation of the "Mint Production Notes". Perhaps the MIRC could provide similar information in conjunction with our regular newsletters.

(3) *MIRC sponsored workshops*
The MIRC could sponsor regional IPM workshops where researchers discuss pest management with growers. This would allow more focused and effective communication between researchers and growers in smaller groups.

3.2 Future research requirements

If mint IPM programs are to focus less on the use of conventional synthetic pesticides, and more on tactics to include biological control, cultural control and safer pesticides, additional research is required. As in the past, the mint industry will continue to investigate practical alternatives to chemical pesticides. A close association with EPA through PESP will hopefully provide early information on promising new technologies. In addition, research on cultural alternatives and economic treatment thresholds should be considered as part of future MIRC sponsored research. The following are research topics that could be considered for future support.

Arthropods

(1) *Registration of selective pesticides in relation to resistance management*
To prevent a future crisis, we need to identify cost effective insecticides that are less disruptive to biological control and are compatible with pesticide resistance management. This strategy is much less effective, however, if pesticide registration takes too long.

(2) *Test selectivity of currently registered pesticides against key pest natural enemies*
Pesticides including terbacil (Sinbar) are known to disrupt pest natural enemies. Each pesticide presently registered should be tested for selectivity against key natural enemies in mint. Testing pesticides in this way should be part of the mint industry's pesticide registration process.

(3) *Determine the optimal timing of pest intervention*
An adequate understanding of pest biology is necessary for properly timing pesticide applications. Correct timing may allow the use of currently registered pesticides to control difficult pests, enable the use of lower pesticide rates, and reduce the necessity of repeat pesticide applications.

(4) *Development and refinement of treatment thresholds and sampling methods*
Treatment thresholds and sampling methods are crucial components of IPM. Without this information, consultants are unable to accurately assess pest importance which leads to wasteful management decisions.

Diseases

(1) *Sampling methods and strain differentiation for Verticillium on mint.*
Planting clean and vigorous rootstock is an important part of mint IPM. To support the mint rootstock industry, and to alleviate grower concerns about whether or not a field

should be planted to mint, basic sampling procedures and bioassays are required to determine the density and virulence of wilt strains.

(2) *Effect of powdery mildew on peppermint.*
Growers are using significant amounts of sulfur to control powdery mildew on peppermint and spearmint. Much of these sulfur applications may not be necessary on peppermint. Unjustified sulfur applications not only increase the cost of production, but also disrupts biological control.

(3) *Affects of agronomic practices, varietal differences and methods of rootstock propagation on mint diseases.*
We know that herbicide use can increase the severity of Verticillium wilt and powdery mildew. It also appears that differences in varieties and methods of rootstock propagation can also influence how mint responds to different diseases. For example, observations suggest that peppermint propagated by merstematic tissue culture is more susceptible to mint rust.

Nematodes

(1) *Management alternatives to disruptive nematicides.*
Management of plant parasitic nematodes has focused primarily on the use of conventional nematicides. Unfortunately, these nematicides are very toxic to non-target organisms and can be rendered ineffective through enhanced microbial degradation (Santo 1993). Research could consider the effects of soil pH, variety type, and plant vigor as components of nematode management.

(2) *Comparison of less disruptive application methods and formulations.*
It appears that conventional nematicides will be a significant component of nematode management for some time yet. Often times these nematicides can be used in ways that are less disruptive to biological control by considering the method of application and formulation used. Examples include, granular formulations, chemigation and impregnation on fertilizer.

(3) *Refinement of economic injury levels and sampling procedures*
Many growers use nematicides on a yearly basis. This practice is not only expensive but is disruptive to biological control. Moreover, this practice selects for soil organisms which rapidly degrade pesticides. Research, including my own, has primarily focused on testing nematicides in severely infested and weakened mint fields. By conducting research in this way, treatment differences are often more easily observed. Based on these results, percentage increases in oil yield from poor stands are extrapolated to healthy stands. I believe such extrapolation is frequently invalid. For example, data from the Oregon State University pesticide use survey shows that average peppermint yields are higher in fields not receiving a nematicide treatment when compared to those that are treated with Vydate (Jeppson 1995). These data suggest that healthy and vigorous

peppermint stands can tolerate a certain amount of stress including nematodes. I would challenge researchers to attack the nematode issue from another angle. We need to ask ourselves: "when is a nematicide not required?" instead of the conventional approach which assumes the usually are needed. To accomplish this goal will require a closer inspection of economic injury over time and reliable sampling methods.

Weeds

(1) *Practical alternatives to conventional herbicides*

Biological control of weeds has been successful mostly in non-crop situations. However, if practical alternatives to conventional herbicides are identified, they should be tested on mint.

(2) *Effect of herbicides on mint diseases*

Based on previous research, it appears that applications of certain herbicides increase the severity of mint diseases. Herbicides may be responsible for economically damaging Verticillium wilt and powdery mildew outbreaks. These potential interactions should be investigated and herbicide use patterns adjusted accordingly.

(3) *Herbicide resistance management*

Several important herbicides registered on mint, for example Sinbar, do not control weeds as effectively as they once did. This is because they have been used too frequently. Because pesticides are more difficult and expensive to register, we need to use them in ways that prolong their useful life.

(4) *Mint injury resulting from herbicide carryover*

Major crop commodity organizations such as soybeans have investigated how herbicides applied to previous crops affect their new plantings. For mint, this research has not been done. It appears that herbicides such as Atrazine on corn, Glean on wheat, and Banvel on wheat, can injure new mint plantings. Information obtained from such research may help explain why certain mint fields fail to produce in cases where other causes have been ruled out.

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